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A Comparative Study of Package Orientation in the Overnight Distribution Environment Utilizing Different Shapes of Shipping Containers

Ritesh A. Rao

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by

Ritesh A Rao

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CERTIFICATE OF APPROVAL

M. S. DEGREE

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In addition, I would like to thank all of the observers who participated in the tests as their results are a vital part of the research in this thesis.

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In addition, I would like to thank all of the observers who participated in the tests as their results are a vital part of the research in this thesis.

Dedication

This thesis is dedicated to my family, my parents, and my friends who have made many sacrifices while I have pursued this goal. Without their love and support I would not have been able to accomplish this goal.

A Comparative Study of Package Orientation in the Overnight Distribution Environment

Utilizing Different Shapes of Shipping Containers

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Abstract

Package orientation is an important aspect to consider during the transit of packages worldwide. As orientation of a package can influence the manual handling and compressible load performance, it becomes important parameter to consider in an overnight distribution environment. Significantly, less amount of research completed in the area of package orientation. Current study involves three different types of packages (Rectangular, Cubic & Flat) and with the help of SENSR™ instrument impact orientations measured at defined time interval. Packages shipped along with measuring instrument to record the data, and collected data analyzed further to understand the orientations percentages for each type of container. Data showed variance in the percentage orientation between all the containers with normal (Z+) orientation being the most significant than the rest and concludes that size and shape have an effect on package orientation.

The information in this thesis will supplement the pre-existing body of knowledge and used for future test procedures

Key words: overnight distribution environment, package orientation, impact.

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Chapter 1.

Introduction

A significant number of packages are damaged during transit. As a direct result, package-shipment companies incur financial losses, McKinlay (2004). A considerable amount of research has been conducted to understand the significant factors that influence damages to packages. Package orientation in overnight distribution is a very important variable to be considered during handling, transport, and storage of the packaged goods, Goodwin (2007). Many products are vulnerable to compression loading or leakage resulting from the improper orientation of the package during transit, which would cause damage to the product. This issue has caused concerns in the overnight distribution environment and has led many packaging researchers to study the package orientation of shipping containers in this environment.

Singh (1998) studied the effect of label location on impact orientation in the small-parcel environment (Study of Package Drop Orientation in the Small Parcel Environment, 1998). In one recent study Singh (2008) evaluated the dynamic events on the "smalls," "Packages with volume less than 13,000 cm3 (800 in3), and longest being 350 mm (14in)" (Dynamic Analysis of "Smalls" in FedEx Next Day Air Shipments), when they were shipped and handled along with the larger packages in the distribution environment. The initial study by Goodwin and Young (2007) investigated the orientation of a cubic, mass-centered specimen in the overnight distribution cycle. The outcomes from this study were intended to develop a profile of the continuous orientation of the package as it moves through the overnight distribution system.

In the most recent study Goodwin et al. (2008) compared the orientation patterns for two specimens that varied in shape and weight: flat (light) versus rectangular (heavy). With the use of the measuring instrument, orientation was measured over time, independent of any impact triggering a recording.

The effect of package orientation on different shapes and sizes of shipping containers is an interesting area of research. This study considers different types and shapes of containers in order to enhance understanding of the effect of package orientation on an overnight shipment passing through the FedEx distribution system. The study will employ a previously used instrumentation device to monitor and record the package orientation in three different axes throughout the FedEx supply chain cycle.

The objective is to further understand whether any correlation exists between different shapes and sizes of shipping containers in regards to the package orientation in the overnight distribution/shipping environment. To that end, with the help of a recently available programmable accelerometer made by SENSR of Elkader, Iowa, USA, measured the orientation over time and performed the comparative analysis as a part of his thesis. The information provided in this thesis is an original study on package orientation and will add to the body of knowledge from previously conducted studies in this area.

Chapter 2.

Literature Review

Research is relatively limited in the area of package orientation in correlation to the overnight distribution environment, although there are several technical papers published on similar topics. This chapter first reviews several papers on similar topics, identifies the initial work done by Goodwin (2008) in the field of package orientation, and summarizes the findings.

Singh (1993) studied the various impacts the packages experience when exposed to the overnight system. His study investigated the overnight parcel delivery environments of Federal Express, United Parcel Service (UPS), and the United States Postal Service (USPS) in the United States. The study measured the vertical drops and lateral impacts that occurred during the handling and sorting operations in the overnight distribution system. The purpose of his study was to quantify the unique handling requirement in an overnight air delivery system. With the help of Dallas Instrument's drop height recorders, various shocks and drop heights were measured in a series of repeated trips from different locations. Data from the recorders were further evaluated for each carrier's drop height, velocity, and average lateral impact. The observed results concluded were 77.8 inches was the highest drop, and 99.5% of all drops measured below 27.5 inches for Federal Express and UPS. For USPS, 99.5% of all drops measured were below 50 inches. Similarly observed lateral drops measured a velocity change of 250 in/sec with 99.5% of all impacts for Federal Express and UPS less than 165 in/sec and 225 in/sec for USPS shipments in an overnight distribution environment.

Singh (1998) studied the effect of label placement on the package-drop orientation in a small-parcel environment. In this study, five different sizes of packages with different weights along with shock data recorders (Lansmont, SAVER) were used to record the drop-impact orientation. Average drop heights for each of the containers were measured and analyzed, and the findings were discussed with the observations. The data utilized for analysis were the outcomes of the impact/shock recorded in the small-parcel environment.

Singh (1998) also studied the effect of "this side up" markings on the package. The study concludes that most of the regular-slotted shipping containers are expected to be in top orientation; however, for space utilization the sorting employees would position the packages in sideways.

The intent of the study was to help packaging professionals develop a suitable test method for the package design process to reduce the damages in shipment.

Dr. J. Singh (2004) studied the dynamics of very lightweight packages of varying sizes in the second-day air express environment. He also intended to propose the test levels for drop testing. Environmental Data Recorder–3C (EDR- 3C), manufactured by Instrumented Sensor Technology, Okemos, MI, USA, was used to measure the shock, vibration, temperature, humidity, and pressure in the packages in the shipping environment.

Five packages with different shapes, sizes, and weights were analyzed to further conclude that size and shape do not have a correlation with the drop heights, and this research suggests that the handling operations element has an effect on all types of packages (light or heavy) in a FedEx second-day air delivery system. This information was the basis for developing new test methods in designing protective packaging.

All the above studies provide information about the impacts/shocks to the packages, but they don't provide any information on package orientation. In addition, all the events are dependent on triggering impacts and not otherwise. It will be interesting to see if there is any instrument that can provide the package orientation information when a package is in an idle condition such as sitting at a warehouse or other zero-impact situations.

Goodwin and Young (2007) studied the effect of package orientation on a cubic container in an overnight distribution environment. A recently available instrument from SENSR was used to study orientation of the package independent of any impact or event to trigger a recording. The data from the instrument was further analyzed, and it was observed that the package spent the majority of time in normal orientation (label on top face). Other orientations were also experienced on the package; however, the time spent was significantly less.

Goodwin et al. (2008) did a comparative study that was completed on a flat and a rectangular shipping container on FedEx overnight distribution environment. The shipping containers were shipped along with the recorders and sent from Rochester, NY, to Grand Rapids, MI, and vice versa. It was observed that the package spent the majority of time in its normal orientation-label-up position. The flat and rectangular containers differed by a few percentages.

Singh et al. (2008) presented a paper where they measured and analyzed the dynamic events which occurred to the small-parcel shipment in the FedEx delivery system. The instruments used were tri-axial recorders (SENSR™ GP1) to measure shock, impact, drop, orientation, and temperature. Three different types of mailers were used, and the recorders were placed inside these mailers and shipped using the FedEx priority overnight. The drop test data was analyzed and compared further in order to develop a test protocol. It was concluded that "smalls" or small-package containers were handled differently from larger packages throughout the distribution environment.

A series of ASTM test methods were reviewed to understand if any one of them focuses on package orientation or has any relationship with it. ASTM D5276 provides test procedures for drop testing loaded shipping containers by free fall; it is suitable for shipping containers that are manually handled during the distribution cycle (ASTM Standard D5276, 2003).

ASTM D642 provides test methods to determine the compressive resistance for shipping containers and unit loads. This procedure is used to measure the ability of containers to withstand compressive forces applied to the faces, edges, or corners of any shipping containers (ASTM Standard D642- 00 2005). ASTM D999 provides test methods for vibration testing of shipping containers and assists in determining the performance of shipping containers in terms of strength and package content protection (ASTM Standard D999- 08, 1996-2009). ASTM 4728 provides a test method for random vibration of shipping containers and assists in assessing the performance of a shipping container with its interior contents and closure with respect to ruggedness or protection (ASTM Standard D4728- 06, 1996-2009).

ASTM 4169 provides standard performance testing procedures for shipping containers by subjecting them to a series of test plans consisting of a sequence of a hazardous element in various distribution cycles (ASTM Standard D4169, 1996-2009).

D4169 gives package designers a method for simulating the performance of new or redesigned packages when distributed via any mode of transport. It provides test methods wherein shipping containers are subjected to typical hazard elements as defined by the ASTM test methods, a series of tests, and type of distribution, conducted in sequence with the package being unopened until the package contents are inspected for any damages to determine the acceptance criteria of the procedure. D4169 provides a list of distribution cycles, referred to as DCs, for truck, rail, air, export, import, and specialized military requirements. Some DCs are for single shipping containers, unitized loads such as palletized boxes. All of these DCs use ASTM test methods as test schedules to simulate specific hazard element such as rough handling, vibration, or warehouse stacking. The sequence of test schedules determines the test plan for each DC; for example, a DC 3, single package environment up to 100 lb (45.4 Kg), requires handling tests, loose load vibration, vehicle vibration, and more handling tests. D4169 also provides 3 levels of assurance, I being the highest intensity, II being medium, and III being the lowest level of intensity, which help to define the level of intensity of the test to be conducted (ASTM Standard D4169- 08).

Similarly, ISTA procedure 3A provides a test series for packaged products for parcel delivery system shipment to help understand how a package or product would withstand transportation hazards. It focuses on different types of packages (standard, small, flat, and elongated packages) commonly distributed by air or ground.

ISTA Project 4AB is a web-based program which generates simulation test plans covering testing for 12 different package types, 4 handling types, and 7 types of load-carrying materials or their combinations. Each test plan is tailored to a particular situation with the help of specific hazard profiles.

Chapter 3.

Hypotheses

Ho – The package orientation is not influenced by the size and shape of the shipping container in the overnight distribution environment.

H1 – The package orientation is influenced by the size and shape of the shipping container in the overnight distribution environment.

Chapter 4.

Methodology

The study consisted of a mixed methodology, with a combination of qualitative and quantitative strategies, to study the various package orientations throughout the distribution network and understand their relationship to handling, transport, and storage operations. Three specimens used for this study were constructed from C-flute corrugated with a minimum ECT of 32 lb/in. The cubic regular-slotted containers (RSCs) measured 280 x 280 x 280 mm (9 x 9 x 9 in.). The flat RSC measured 38.7 x 31.1 x 8.3 cm (15.25 x 12.25 x 3.25 in.), and the rectangular RSC was 30.5 x 25.4 x 26.7 cm (12 x 10 x 10.5 in.). The flat specimen weighed 0.86 kg (1.90 lb.), and the larger rectangular cube weighed 2.77 kg (6.10 lb.). See Figures 1, 2, and 3. Polyethylene foam was used to hold the instrument and act as a fixture; it had nothing to do with the cushioning, as only the orientation is measured. A mass-centered specimen was created that would not influence its orientation.

Figure 1. Regular Slotted Cubic Container.

Figure 2. Flat Regular Slotted Container.

Figure 3. Rectangular RSC.

Instrumentation Used:

In order to achieve the objectives of this study, data logger/recorders were used to collect the field data that could be used to further develop test methods to simulate the overnight distribution environment. The package orientation-measuring instrument used in the study was a SENSR Model GP1 programmable accelerometer made by Reference LLC, Elkader, IA, USA, and www.sensr.com. The dimension for the instrument was 10x4 cm (3.875 x 1.675 in.).

Figure 4. SENSR™ data logger / recorder.

Table 1. Specifications of GP1 Accelerometer

GP1 Programmable Accelerometer	
Size:	3.935" x 2.500" x 1.140"
Weight with batteries:	8.2 oz
Housing material:	Billet Aluminum
Status indicator:	Tri-color LED
Power:	2 - AA batteries
Battery life:	more than 40 days
Accelerometer type:	3-axis MEMS
Reporting resolution:	.001g
Useful measuring range:	.050g - 12g
Frequency response:	DC - 50 Hz
Sampling rate:	100 samples / sec
Shock survival limit:	1200g - 5msec
Memory capacity:	572,000 readings
Device temperature range:	-4 to 176 degrees F

The SENSR GP1 is a 3-axis recording accelerometer instrument designed to record and evaluate dynamic environmental events. The GP1 can record up to 40 days of field data, which can be used to create concise graphs and tables for easy-to-understand evaluations and comparisons. It assists engineers and designers in measuring real-world data for fact-based decision-making and assists in eliminating any incorrect assumptions or guesswork.

The instrument was positioned in the center of the container in a polyethylene foam fixture supported by die-cut corrugated inserts. Each specimen had a glued manufacturer's joint, taped flaps, and the shipping label placed on the top face. Container, instrument, and support fixture weighed a total of 0.45 kg (1.0 lb.). See Figure 5 for the arrangement of the SENSR unit inside the shipping container.

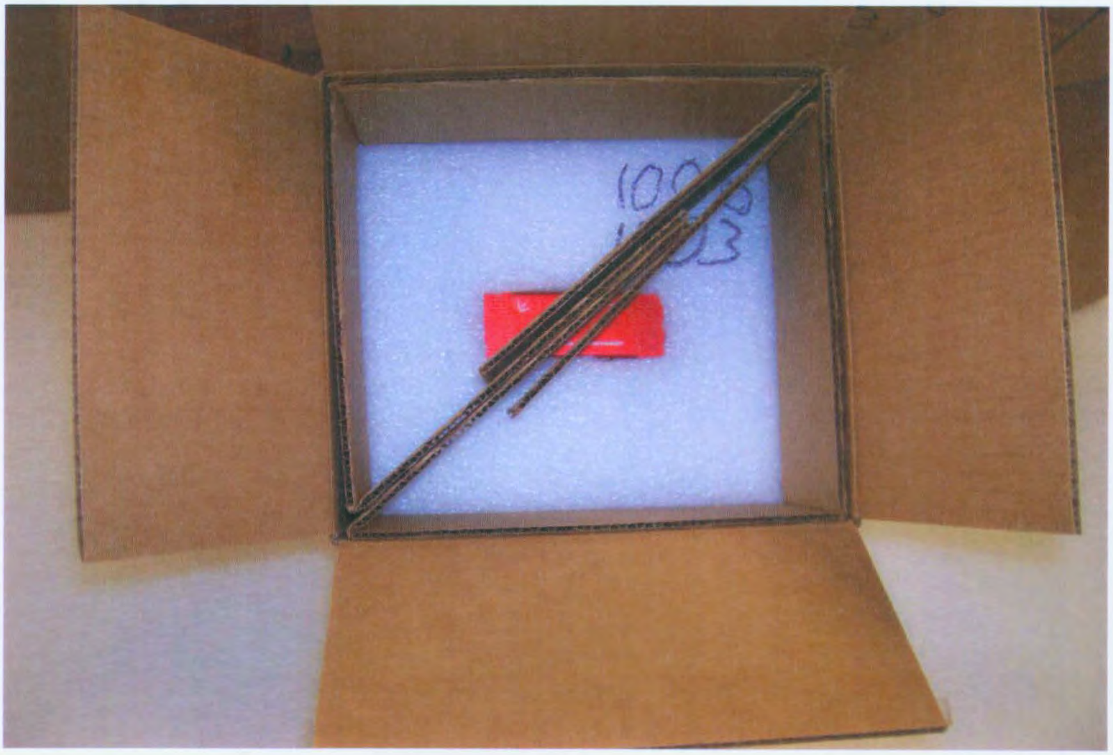


Figure 5. SENSR in shipping container.

A set of programmable units was sent repeatedly through the FedEx overnight distribution system from Rochester, NY, to locations in Grand Rapids, MI, and Elkader, IA. Each type of package (cubic, flat, and rectangular) made repeated round trips between these destinations.

The epoch settings for recording orientation readings were set at 20 seconds for cubic and 15 seconds for flat and rectangular throughout the duration of each trip. It was then downloaded into a computer system via a USB cable connecting the instrument to a computer. The data was downloaded into an Excel spreadsheet for further analysis and interpretation of logistical operations taking place in transit.

The comparative study on each type of orientation data was completed using Microsoft Excel. Graphical representation of the package is shown in Figure 6 below:

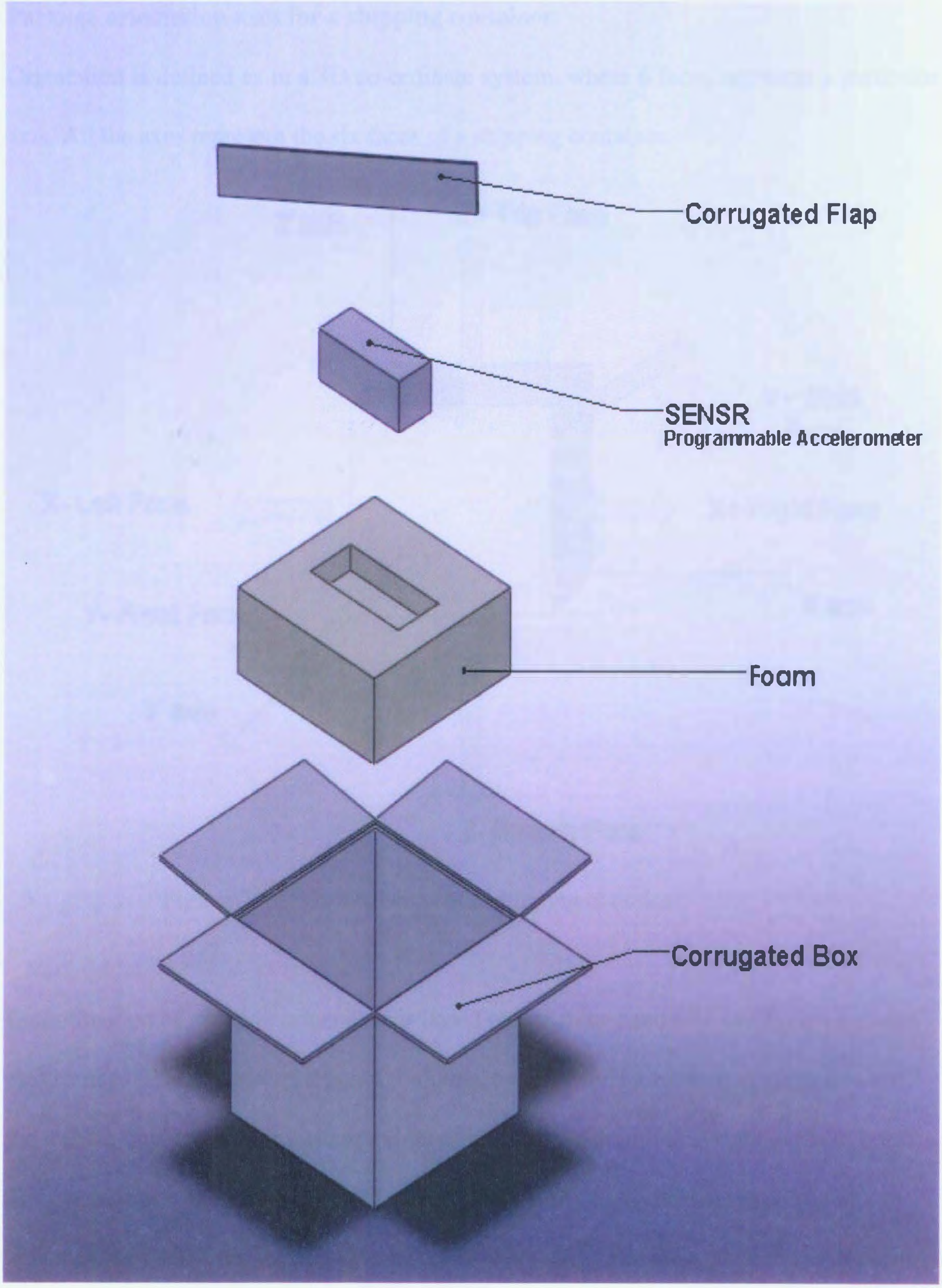


Figure 6. Schematic diagram of arrangement of shipping containers.

Package orientation axes for a shipping container:

Orientation is defined as in a 3D co-ordinate system, where 6 faces represent a particular axis. All the axes represent the six faces of a shipping container.

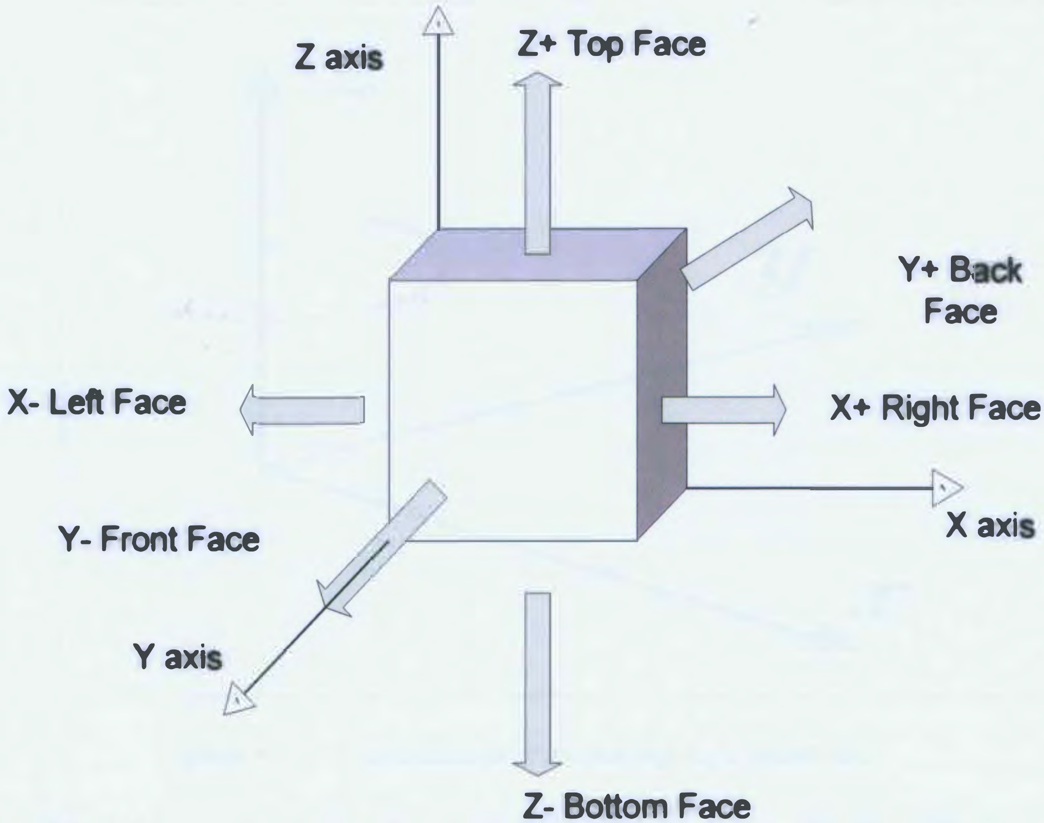


Figure 7. 3D Co-ordinates of a shipping container.

Determination of package orientation is based on the right-hand rule similar to electromagnetism; however, it is not the same, because the index finger points forward, the middle finger is bent inward at a right angle, and the thumb is at right angle to both. The three fingers indicate x-, y-, and z- directions in the right-hand system. The thumb indicates the x-axis, the index finger indicates the y- axis, and the middle finger indicates the z- axis.

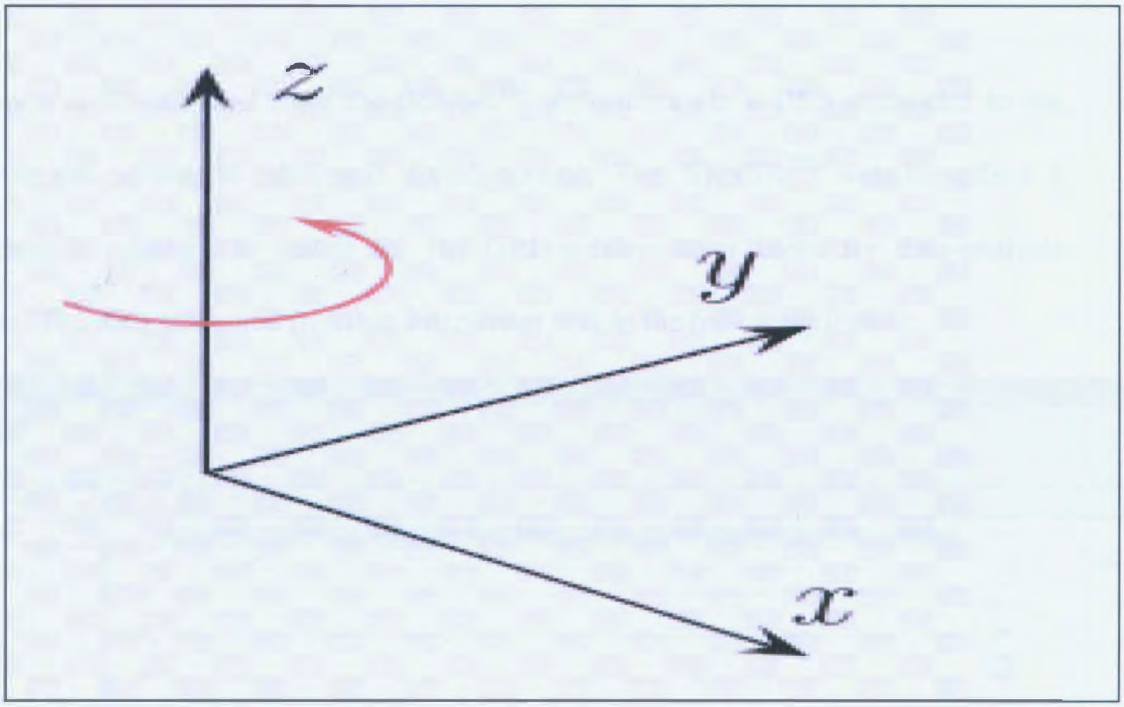


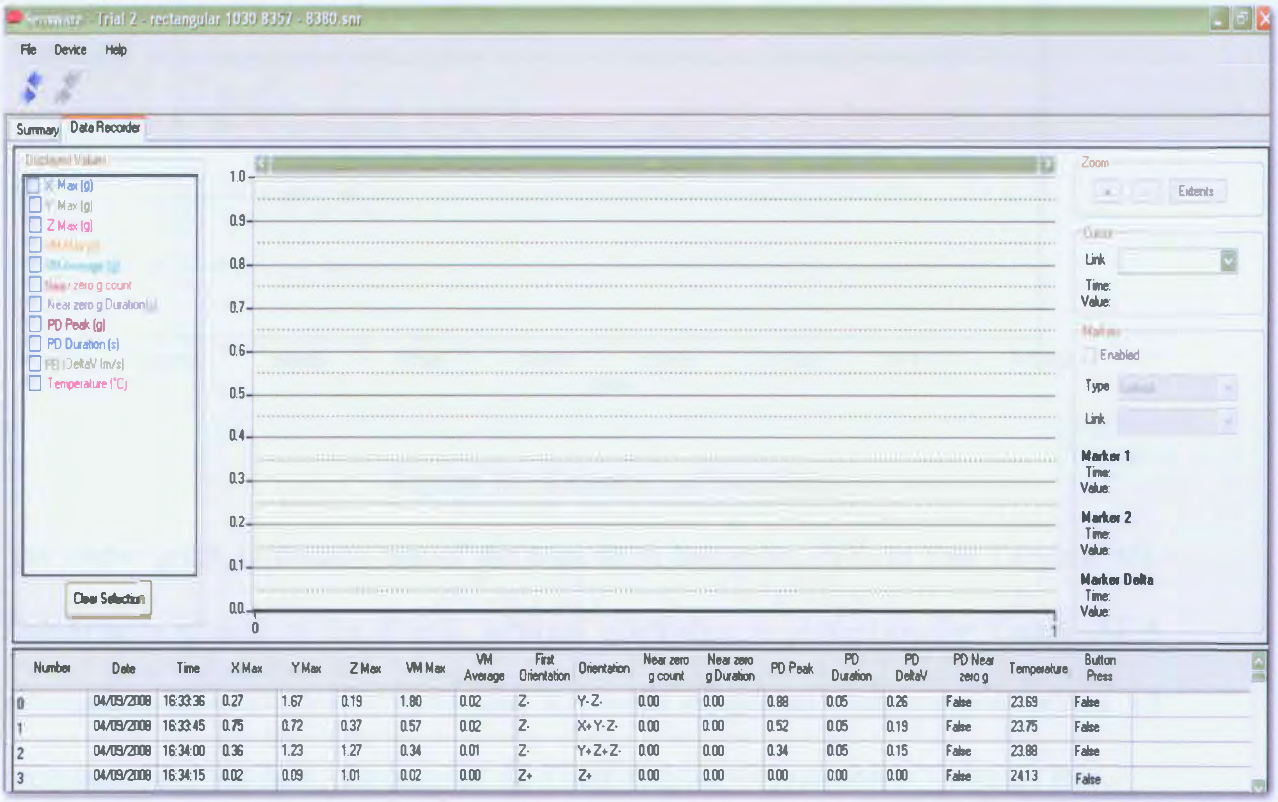
Figure 8. 3D Co-ordinates representing right-hand rule.

The above figure represents the rule of the right hand for 3D co-ordinates; the three fingers indicate x-, y-, and z- directions in the right-hand system. The thumb indicates the x-axis; the index finger indicates the y- axis, and the middle finger indicates the z- axis (www.wikipedia.com).

Chapter 5.

Data analysis and results

The data was downloaded from the SENSR™ instrument via a USB connector to the computer and stored in Microsoft Excel format. The SENSR™ website offers a downloadable program to install for the GP1 accelerometer users for data-analysis purposes. The data presented from the instrument was in the following format:



Number	Date	Time	X Max	Y Max	Z Max	VM Max	VM Average	First Orientation	Orientation	Near zero g count	Near zero g Duration	PD Peak	PD Duration	PD DeltaV	PD Near zero g	Temperature	Button Press
0	04/09/2008	16:33:36	0.27	1.67	0.19	1.80	0.02	Z-	Y-Z-	0.00	0.00	0.88	0.05	0.26	False	23.69	False
1	04/09/2008	16:33:45	0.75	0.72	0.37	0.57	0.02	Z-	X+Y-Z-	0.00	0.00	0.52	0.05	0.19	False	23.75	False
2	04/09/2008	16:34:00	0.36	1.23	1.27	0.34	0.01	Z-	Y+Z+Z-	0.00	0.00	0.34	0.05	0.15	False	23.88	False
3	04/09/2008	16:34:15	0.02	0.09	1.01	0.02	0.00	Z+	Z+	0.00	0.00	0.00	0.00	0.00	False	24.13	False

Figure 9. Data from the SENSR Instrument.

This above data was further imported into an Excel spreadsheet in CSV (Comma Separated Value) format where all orientation events against time were captured for respective trips. The SENSR™ software program allows integration of this information in a format that is very user friendly for data analysis. The provided information also includes Net zero G Count, PD Peak, and PD Duration, which will not be a part of this study.

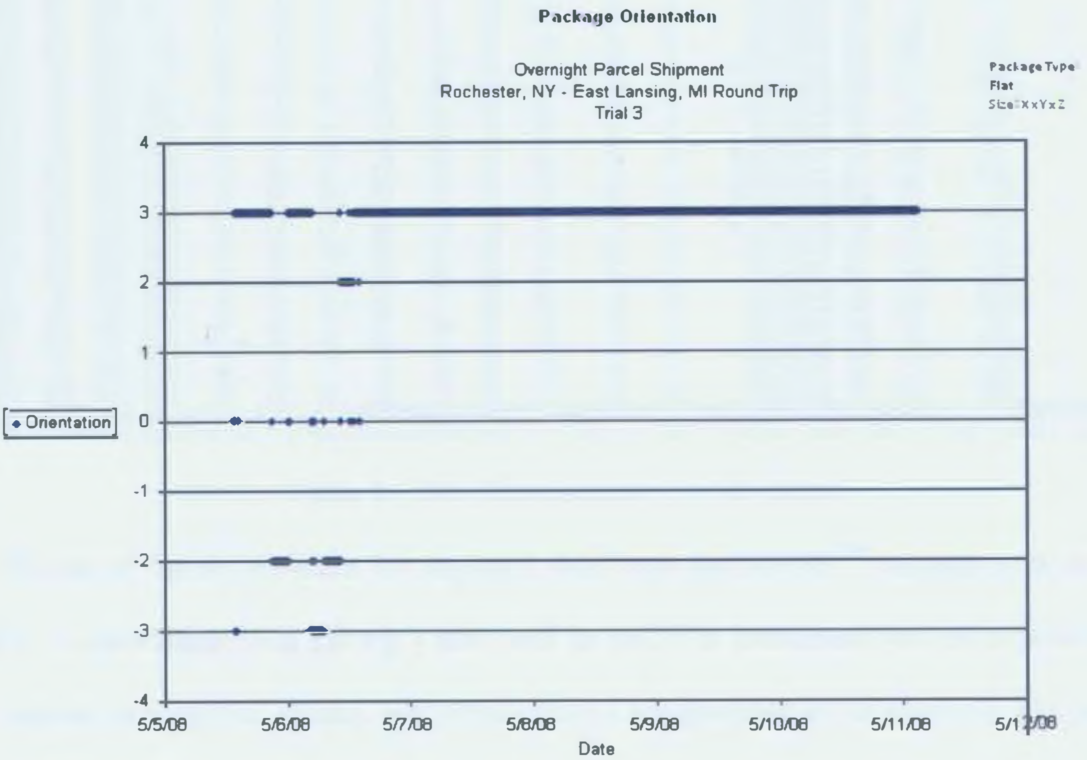
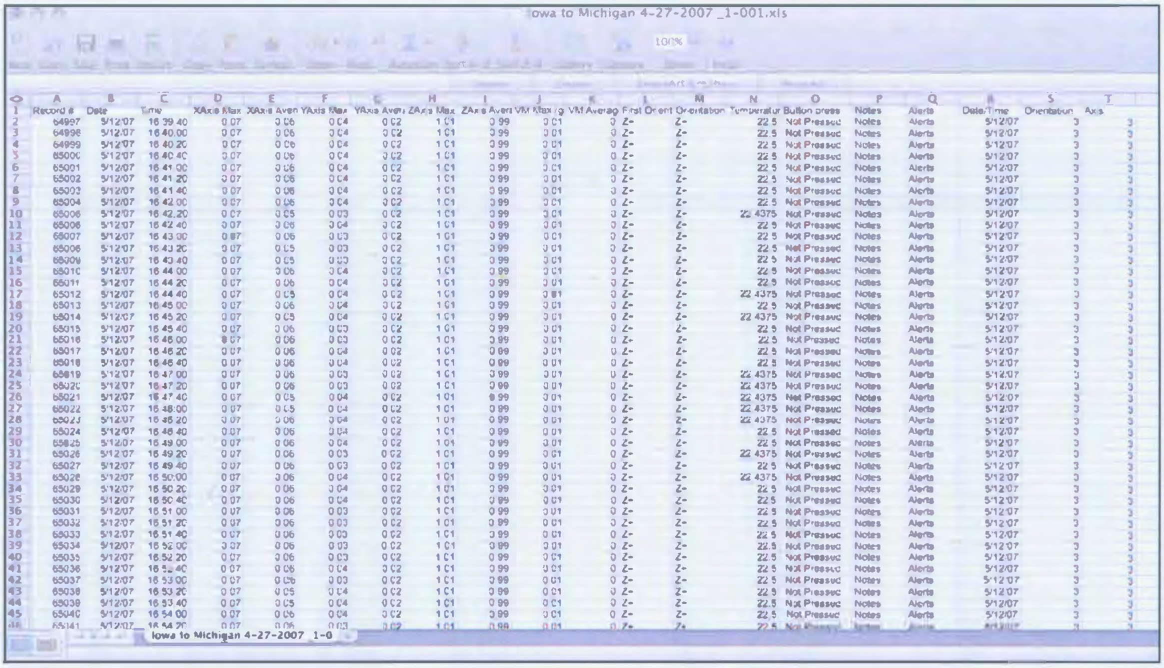


Figure 10 . Orientation-Time Plot.

The above graph represents one of the trips from Rochester, NY, to East Lansing, MI. Date/time is plotted on the X-axis, whereas orientation is plotted on the Y-axis. All 6 orientations (Z+, Z-, Y+, Y-, X+ and X-) were represnted with numbers where +3 represents (Z+) top face, -3 represents (Z-) bottom face, +2 represents (X+) right face, -2 represents (X-) left face, +1 represents (+Y) back face, -1 represents the front face (-Y), and 0 (zero) represents the time when the package was in an idle state. The reason for doing this was the ease of plotting the graph in Microsoft Excel.



Iowa to Michigan 4-27-2007 _1-001.xls

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	Record #	Date	Time	XAxis Max	XAxis Aver	YAxis Max	YAxis Aver	ZAxis Max	ZAxis Aver	VM Max (g	VM Averag	First Orient	Orientation	Temperatur	Button press	Notes	Alerts	Date/Time	Orientation	Axis
2	64997	5/12/07	16:39:40	0.07	0.06	0.04	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
3	64998	5/12/07	16:40:00	0.07	0.06	0.04	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
4	64999	5/12/07	16:40:20	0.07	0.06	0.04	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
5	65000	5/12/07	16:40:40	0.07	0.06	0.04	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
6	65001	5/12/07	16:41:00	0.07	0.06	0.04	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
7	65002	5/12/07	16:41:20	0.07	0.06	0.04	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
8	65003	5/12/07	16:41:40	0.07	0.06	0.04	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
9	65004	5/12/07	16:42:00	0.07	0.06	0.04	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
10	65005	5/12/07	16:42:20	0.07	0.05	0.03	0.02	1.01	0.99	0.01	0	Z-	Z-	22.4375	Not Pressed	Notes	Alerts	5/12/07	3	3
11	65006	5/12/07	16:42:40	0.07	0.06	0.04	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
12	65007	5/12/07	16:43:00	0.07	0.06	0.03	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
13	65008	5/12/07	16:43:20	0.07	0.05	0.03	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
14	65009	5/12/07	16:43:40	0.07	0.05	0.03	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
15	65010	5/12/07	16:44:00	0.07	0.06	0.04	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
16	65011	5/12/07	16:44:20	0.07	0.06	0.04	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
17	65012	5/12/07	16:44:40	0.07	0.05	0.04	0.02	1.01	0.99	0.01	0	Z-	Z-	22.4375	Not Pressed	Notes	Alerts	5/12/07	3	3
18	65013	5/12/07	16:45:00	0.07	0.06	0.04	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
19	65014	5/12/07	16:45:20	0.07	0.05	0.04	0.02	1.01	0.99	0.01	0	Z-	Z-	22.4375	Not Pressed	Notes	Alerts	5/12/07	3	3
20	65015	5/12/07	16:45:40	0.07	0.06	0.03	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
21	65016	5/12/07	16:46:00	0.07	0.06	0.03	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
22	65017	5/12/07	16:46:20	0.07	0.06	0.04	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
23	65018	5/12/07	16:46:40	0.07	0.06	0.04	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
24	65019	5/12/07	16:47:00	0.07	0.06	0.03	0.02	1.01	0.99	0.01	0	Z-	Z-	22.4375	Not Pressed	Notes	Alerts	5/12/07	3	3
25	65020	5/12/07	16:47:20	0.07	0.06	0.03	0.02	1.01	0.99	0.01	0	Z-	Z-	22.4375	Not Pressed	Notes	Alerts	5/12/07	3	3
26	65021	5/12/07	16:47:40	0.07	0.05	0.04	0.02	1.01	0.99	0.01	0	Z-	Z-	22.4375	Not Pressed	Notes	Alerts	5/12/07	3	3
27	65022	5/12/07	16:48:00	0.07	0.05	0.04	0.02	1.01	0.99	0.01	0	Z-	Z-	22.4375	Not Pressed	Notes	Alerts	5/12/07	3	3
28	65023	5/12/07	16:48:20	0.07	0.06	0.04	0.02	1.01	0.99	0.01	0	Z-	Z-	22.4375	Not Pressed	Notes	Alerts	5/12/07	3	3
29	65024	5/12/07	16:48:40	0.07	0.06	0.04	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
30	65025	5/12/07	16:49:00	0.07	0.06	0.04	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
31	65026	5/12/07	16:49:20	0.07	0.06	0.03	0.02	1.01	0.99	0.01	0	Z-	Z-	22.4375	Not Pressed	Notes	Alerts	5/12/07	3	3
32	65027	5/12/07	16:49:40	0.07	0.06	0.03	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
33	65028	5/12/07	16:50:00	0.07	0.06	0.04	0.02	1.01	0.99	0.01	0	Z-	Z-	22.4375	Not Pressed	Notes	Alerts	5/12/07	3	3
34	65029	5/12/07	16:50:20	0.07	0.06	0.04	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
35	65030	5/12/07	16:50:40	0.07	0.06	0.04	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
36	65031	5/12/07	16:51:00	0.07	0.06	0.03	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
37	65032	5/12/07	16:51:20	0.07	0.06	0.03	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
38	65033	5/12/07	16:51:40	0.07	0.06	0.03	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
39	65034	5/12/07	16:52:00	0.07	0.06	0.03	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
40	65035	5/12/07	16:52:20	0.07	0.06	0.03	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
41	65036	5/12/07	16:52:40	0.07	0.06	0.04	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
42	65037	5/12/07	16:53:00	0.07	0.06	0.03	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
43	65038	5/12/07	16:53:20	0.07	0.05	0.04	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
44	65039	5/12/07	16:53:40	0.07	0.05	0.04	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
45	65040	5/12/07	16:54:00	0.07	0.06	0.04	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	Not Pressed	Notes	Alerts	5/12/07	3	3
46	65041	5/12/07	16:54:20	0.07	0.06	0.03	0.02	1.01	0.99	0.01	0	Z-	Z-	22.5	[illegible]	[illegible]	[illegible]	[illegible]	3	3

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Table 1. Data Representation in MS Excel.

The above figures represent the imported data from the SENSR™ instrument in an MS Excel spreadsheet from the trip's start until its end. The instrument was set to record the orientation positions, shocks, and vibrations at a programmed set of intervals. The stored data was downloaded and further utilized for analysis purposes, as well as for testing the hypothesis. It was available throughout the trip to permit study of the package's behavior during the transit times, when only those data points were selected.

The time when the package was sitting idle was eliminated from the analysis. The live transition time set of data was used for further analysis to estimate the time spent in each particular orientation. To validate our hypothesis of whether the package size and shape do influence its orientation, the collected data was analyzed for a chi-square test. The randomized data was selected from all of the trials and utilized for analysis purposes. A chi-square test was used to validate the hypotheses because the dataset is not normal. Three thousand (3,000) data points from all of the containers were selected. Through the use of the Microsoft Excel randomizer, the data was randomized, and 1,000 additional data points were taken for analysis purposes, as shown in Table 1, below.

	A	B	C	D	E	F	G	H	I
1	Sr. No.	Cube	Rect	Flat		Sr. No.	3000 Values	Random Number Generator	Data
2	1	Z- Cube	X- Rect	Z- Flat		1	Z- Cube	294	Z- Cube
3	2	Z- Cube	Z- Rect	Z- Flat		2	Z- Cube	529	Z- Cube
4	3	Z- Cube	Z- Rect	Z- Flat		3	Z- Cube	2391	Z- Flat
5	4	Z- Cube	Z- Rect	Z- Flat		4	Z- Cube	778	Z- Cube
6	5	Z- Cube	X- Rect	Z- Flat		5	Z- Cube	1494	Z- Rect
7	6	Z- Cube	X- Rect	Z- Flat		6	Z- Cube	403	Z- Cube
8	7	Z- Cube	Z- Rect	Y- Flat		7	Z- Cube	48	Z- Cube
9	8	Z- Cube	Z- Rect	Z- Flat		8	Z- Cube	1855	X- Rect
10	9	Z- Cube	X- Rect	Z- Flat		9	Z- Cube	590	Z- Cube
11	10	Z- Cube	Z- Rect	Z- Flat		10	Z- Cube	1010	Z- Rect
12	11	Z- Cube	Z- Rect	Z- Flat		11	Z- Cube	579	Z- Cube
13	12	Z- Cube	Z- Rect	Z- Flat		12	Z- Cube	2633	Z- Flat
14	13	Z- Cube	Z- Rect	Z- Flat		13	Z- Cube	1498	Z- Rect
15	14	Z- Cube	Z- Rect	Z- Flat		14	Z- Cube	513	Z- Cube
16	15	Z- Cube	X- Rect	Z- Flat		15	Z- Cube	2322	Z- Flat
17	16	Z- Cube	X- Rect	Z- Flat		16	Z- Cube	1491	X- Rect
18	17	Z- Cube	Z- Rect	Z- Flat		17	Z- Cube	277	Z- Cube
19	18	Z- Cube	Z- Rect	Z- Flat		18	Z- Cube	91	Z- Cube
20	19	Z- Cube	Z- Rect	Z- Flat		19	Z- Cube	2168	Y- Flat
21	20	Z- Cube	Z- Rect	Y- Flat		20	Z- Cube	471	Z- Cube
22	21	Z- Cube	Z- Rect	Y- Flat		21	Z- Cube	2742	Z- Flat
23	22	Z- Cube	X- Rect	X- Flat		22	Z- Cube	2917	Z- Flat
24	23	Z- Cube	Z- Rect	Y+ Flat		23	Z- Cube	691	Z- Cube
25	24	Z- Cube	X- Rect	Z- Flat		24	Z- Cube	598	Z- Cube
26	25	Z- Cube	X- Rect	Z- Flat		25	Z- Cube	832	Z- Cube
27	26	Z- Cube	X- Rect	Z- Flat		26	Z- Cube	60	Z- Cube
28	27	Z- Cube	Z- Rect	Z- Flat		27	Z- Cube	2107	Y- Flat
29	28	Z- Cube	X- Rect	Z- Flat		28	Z- Cube	309	Z- Cube
30	29	Z- Cube	Z- Rect	Y+ Flat		29	Z- Cube	1020	Z- Rect
31	30	Z- Cube	Z- Rect	Z- Flat		30	Z- Cube	2006	Z- Flat
32	31	Z- Cube	X- Rect	Z- Flat		31	Z- Cube	2587	Z- Flat
33	32	Z- Cube	Z- Rect	Z- Flat		32	Z- Cube	595	Z- Cube
34	33	Z- Cube	Z- Rect	Z- Flat		33	Z- Cube	2121	Z- Flat
35	34	Z- Cube	Z- Rect	Z- Flat		34	Z- Cube	494	Z- Cube
36	35	Z- Cube	X- Rect	Z- Flat		35	Z- Cube	1490	Z- Rect
37	36	Z- Cube	X- Rect	Z- Flat		36	Z- Cube	155	Z- Cube
38	37	Z- Cube	Z- Rect	Z- Flat		37	Z- Cube	1998	Z- Rect
39	38	Z- Cube	Z- Rect	Y- Flat		38	Z- Cube	1927	Z- Rect
40	39	Z- Cube	X- Rect	Z- Flat		39	Z- Cube	1712	Z- Rect

Table 2. Data in a Tabular Format.

The formula to calculate the chi-square is shown below.

Chi-Square Formula and Degrees of Freedom

$$\chi^2 = \sum \frac{(f(a) - f(e))^2}{f(e)}$$

χ^2 = Chi-square

$f(a)$ = actual frequency or number of observations in a cell

$f(e)$ = expected frequency or number of observations in a cell in the theoretical distribution

$\sum$ = symbol for "summation" the differences are cumulative

Alpha value = 5		Alpha Value = 1	
Degrees of freedom	**Value**	**Degrees of freedom**	**Value**
1	3.84	1	6.63
2	5.99	2	9.21
3	7.82	3	11.3
4	9.49	4	13.3
5	11.10	5	15.1
6	12.60	6	16.8
7	14.10	7	18.5
8	15.50	8	20.1
9	16.90	9	23.2
10	18.30	10	24.7
11	19.70	11	26.2
12	21.00	12	27.7
13	22.40	13	29.1
14	23.70	14	30.6
15	25.00	15	30.6
16	26.30	16	32.0
17	27.60	17	33.4
18	28.90	18	34.8
19	30.10	19	36.2
20	31.40	20	37.6
21	32.70	21	38.9
22	33.90	22	40.3
23	35.20	23	41.6
24	36.40	24	43.0
25	37.70	25	44.3
26	38.90	26	45.6
27	40.10	27	47.0
28	41.30	28	48.3
29	42.60	29	49.6
30	43.80	30	50.9

Table 3. Degrees of Freedom.

The degree of freedom (DOF) was calculated utilizing the formula (m-1)*(n-1), where m denotes the 6 faces of the cube and n denotes 3 for types of containers. The DOF is 10, and the corresponding value will be 18.30 for alpha value = 5. This value will be critical in accepting or rejecting the hypothesis. The observed values were the actual values from the 1,000 randomized data from the instrument, whereas expected values were computed.

From the above DOF table, in order for DOF conditions to accept the hypotheses, the following must be indicated:

If the chi-square value is more than 18.30, then accept Ho, i.e., the size and the shape of the shipping container influences the package orientation.

Ho – The package orientation is influenced by the size and the shape of the shipping container in the overnight distribution environment.

H1 – The package orientation is <u>not</u> influenced by the size and the shape of the shipping container in the overnight distribution environment.

If the chi-square value is less than 18.30, then reject the other hypothesis because the size and the shape of the shipping container do not influence the package orientation.

The following table represents the information from 1,000 randomized data points for all three containers as being observed and expected readings; "observed" = the real downloaded information and "expected" = calculated.

OBSERVED VALUES

	Z +	Z -	Y +	Y -	X +	X -	Total
Cube	**360.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	360.00
Rectangle	**4.00**	**247.00**	**2.00**	**0.00**	**0.00**	**87.00**	340.00
Flat	**230.00**	**2.00**	**15.00**	**52.00**	**0.00**	**1.00**	300.00
Total	594.00	249.00	17.00	52.00	0.00	88.00	1,000.00

EXPECTED VALUES

	Z +	Z -	Y +	Y -	X +	X -	
Cube	**213.84**	**89.64**	**6.12**	**18.72**	**0.00**	**31.68**	360.00
Rectangle	**201.96**	**84.66**	**5.78**	**17.68**	**0.00**	**29.92**	340.00
Flat	**178.20**	**74.70**	**5.10**	**15.60**	**0.00**	**26.40**	300.00
	594.00	249.00	17.00	52.00	0.00	88.00	1,000.00

Table 4. Observed and Expected Values.

The further breakdown of the formula was computed in a tabular format to calculate the chi-square value. See Table 4 below, where "O" = observed and "E" = expected.

O	E	O-E	(O-E)^2	[(O-E)^2]/E
360.00	213.84	146.16	21,362.75	99.90
0.00	89.64	-89.64	8,035.33	89.64
0.00	6.12	-6.12	37.45	6.12
0.00	18.72	-18.72	350.44	18.72
0.00	0.00	0.00	0.00	0.00
0.00	31.68	-31.68	1,003.62	31.68
4.00	201.96	-197.96	39,188.16	194.04
247.00	84.66	162.34	26,354.28	311.30
2.00	5.78	-3.78	14.29	2.47
0.00	17.68	-17.68	312.58	17.68
0.00	0.00	0.00	0.00	0.00
87.00	29.92	57.08	3,258.13	108.89
230.00	178.20	51.80	2,683.24	15.06
2.00	74.70	-72.70	5,285.29	70.75
15.00	5.10	9.90	98.01	19.22
52.00	15.60	36.40	1,324.96	84.93
0.00	0.00	0.00	0.00	0.00
87.00	26.40	60.60	3,672.36	139.10
			SUM	1,209.51

Table 5. Breakdown of Chi-Square Formula.

We see that the chi-square value is 1,209.51, which is more than 18.30. Hence, we will accept our hypothesis that size and shape do affect the package orientation.

The value of chi-square helps to conclude that for three containers, different shapes and sizes do affect the package orientation in an overnight distribution environment.

Chapter 6.

Conclusion

This study, in conjunction with previously held research in the same environment, is the comparative analysis of three types of packages in the overnight distribution environment. Table 1 represents the orientation of each type of shipping container. When measured, the cube, rectangular, and flat packages spent 100%, 73.7%, and 69%, respectively, of their time in the normal, and thus the strongest, orientation (Z+), in which the label was placed on the top face of each package.

In ASTM D 4577, where the load is generally tested in top-to-bottom orientation, which is the normal orientation (Z+) for compression resistance of a shipping container, this testing method co-relates to our earlier conclusion that normal orientation is the most significant. ASTM D5487, the test method for simulated drop of loaded containers by shock machines, recommends testing the parcel on its most stable orientation, which happens to be normal orientation (Z+) for any parcel. Similarly, 49 CFR, 172.312 (a), a section for liquid hazardous materials in non-bulk packaging, indicates that the package should always be marked in an upward direction, which would be the normal orientation. This is in support of our earlier conclusion that normal orientation (Z+) is the strongest of all as the flute construction is in a vertical direction (orientation) with the box opening at the top.

From the chi-square test that we performed on the data obtained via the field study using the SENSR instrument, we should accept our hypothesis that different container sizes and shapes do have an effect on orientation, and we should reject the other hypotheses in the real-world overnight distribution environment where space utilization is more critical than package orientation (except when packages are scanned), as there is no statistically significant difference. The information in this thesis will supplement the pre-existing body of knowledge and used for future test procedures.

Recommendations for Further Study

This study could be extended to identify other areas where the SENSR instrument can be utilized for other distribution studies. Further recommendations are:

1. A similar study can be conducted for different types of distribution cycles or methods of services (2-day priority, international, etc.) to expand the study in order to see whether any relationship exists with other distribution cycles.
2. A similar experiment can be conducted using different carriers, such as United Parcel Service (UPS) and/or United States Postal Service (USPS), to understand whether any correlation exists among the handling operations in an overnight distribution environment.
3. RFID (Radio-Frequency Identification-tagged) packages should be similarly tracked and studied to reveal how the package orientation would correlate against a manually placed shipping label, because RFID would eliminate the manual handling of the package and would likely change the need to place it in the normal orientation Z+.

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